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ABSTRACT

Potential impacts of aerosol radiative forcing on climate have generated considerable recent interest. An important consideration in estimating the forcing from various aerosol components is the spectral resolution used for the solar radiative transfer calculations. In this paper, we examine the spectral resolution required from the viewpoint of overlapping spectrally varying aerosol properties with other cross-sections. We develop a diagnostic for comparing different band choices and investigate the impact of these choices on the radiative forcing calculated for typical sulfate and biomass aerosols.

1. INTRODUCTION

Potential impacts of aerosol radiative forcing on climate have generated considerable recent interest. Concerns have been expressed regarding possible changes in the global energy budget because of variations in the clear sky albedo (direct effects) and variations in cloud optical properties (indirect effects). In Chuang et al., (1995), we have previously estimated global aerosol forcing using source emission inventories with a coupled climate/chemistry model. Given the mass distributions generated by the coupled model and precomputed fits of aerosol spectral optical properties, radiative forcing calculations were done within the framework of one year climate/chemistry model scenarios.

An important consideration in estimating the forcing from various aerosol components is the spectral resolution used for the solar radiative transfer calculations. To achieve the required computational economy, UV-visible radiative transfer models used within climate models have commonly been limited to a spectral resolution of one to four bands. In general, only absorption by ozone and Rayleigh scattering were considered in determining the required resolution. Within this framework, the determination of the needed spectral resolution and the method for calculating band averaged cross-sections have been discussed by Stamnes and Tsay (1990) and Chou (1992).

In this paper, we evaluate the spectral resolution required from the viewpoint of overlapping spectrally varying aerosol properties with other cross-sections. We develop a diagnostic for comparing different band choices and investigate the impact of these choices on radiative forcing calculated for typical sulfate and biomass aerosols.

2. A SIMPLE DIAGNOSTIC TO ESTIMATE THE SPECTRAL BANDING ERROR

In this section, we develop a diagnostic for comparing the accuracy of different choices in UV-visible spectral banding. The diagnostic is based on the relative error in overlapping two components due to the solar-flux weighted spectral covariance between them. In the examples given we focus on covariances between the specific extinction of aerosols with the spectral absorption of ozone. The motivation for developing this diagnostic is to predict the adequacy of a banding choice before fully implementing it within a radiative transfer model. To impel this study further, we show the relative spectral variation of several atmospheric components in Figure 1. Solar fluxes and molecular cross-sections are taken from WMO (1985).

The solar-flux weighted band transmissivity of a two component path length can be written as

$$T_{12} = \frac{\int_{\Delta\lambda} S(\lambda)\; e^{-k_1(\lambda)u_1}\, e^{-k_2(\lambda)u_2}\; d\lambda}{\int_{\Delta\lambda} S(\lambda)\; d\lambda} \tag{1}$$

where $S(\lambda)$ is the spectral solar flux at the top of the atmosphere, k_1 and k_2 are extinction cross sections, and u_1 and u_2 are component path lengths. In the UV-Visible region, where gaseous absorption (mainly O_3) does not in general

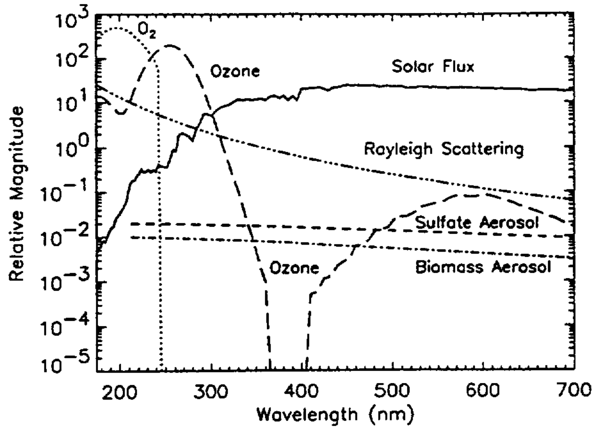

Figure 1: Relative spectral variation of solar flux and extinction coefficients of various atmospheric constituents. The vertical placement of individual curves is arbitrary.

have line structure and scattering by molecules and aerosols are also smoothly varying, single average cross-sections can be used over an entire band. Anticipating this approximation, we express the component cross-sections as band averages and variations from those averages, yielding

$$T_{12} = \frac{\int_{\Delta\lambda} S(\lambda)\, e^{-(\bar{k}_1 + \acute{k}_1(\lambda))u_1}\, e^{-(\bar{k}_2 + \acute{k}_2(\lambda))u_2}\, d\lambda}{\int_{\Delta\lambda} S(\lambda)\, d\lambda} . \qquad (2)$$

If we next linearize the exponentials in Eqn. 2, we obtain the expression

$$T_{12} = 1 - \bar{k}_1 u_1 - \bar{k}_2 u_2 + \bar{k}_1 \bar{k}_2 u_1 u_2 \left\{ 1 + \frac{\int_{\Delta\lambda} S(\lambda)\, \acute{k}_1(\lambda)\, \acute{k}_2(\lambda)\, d\lambda}{\bar{k}_1 \bar{k}_2 \int_{\Delta\lambda} S(\lambda)\, d\lambda} \right\} \qquad (3)$$

In Eqn. 3, the lowest order overlapping error is clearly from the weighted covariance of the two components of the band given by the last term on the right. While the linearized treatment of Eqn. 3 is not accurate enough for most transmission calculations, radiative forcing calculations done below verify that it is accurate enough to form the basis for a useful error diagnostic that is independent of specific absorber amounts. Noting that a useful diagnostic for the entire UV-visible spectral region should be cumulative over all bands and be weighted by the relative solar flux in each band , i, we suggest a diagnostic of the total banding given by

$$\xi = \left(\sum_i \left(\frac{\int_{\Delta\lambda} S(\lambda)\, \acute{k}_1(\lambda)\, \acute{k}_2(\lambda)\, d\lambda}{\bar{k}_1 \bar{k}_2 \int_{UV\text{-}Vis} S(\lambda)\, d\lambda} \right)_i^2 \right)^{\frac{1}{2}} . \qquad (4)$$

In Table 2, we present the results of applying the diagnostic given by Eqn. 4 to the three spectral bandings shown in Table 1. Results shown are for the overlap of ozone with typical sulfate and biomass burning aerosols. Specific extinctions for both aerosol types were estimated at 70% relative humidity following procedures described previously by Chuang et al. (1995). The biomass burning aerosol was assumed to be composed of 20% black carbon by dry weight. For consistency with Eqns. 3 and 4 the ozone cross-sections used as part of the diagnostic calculation were simple flux-weighted (Chandrasekhar) means. The ozone cross-sections used in the forcing calculations discussed below were determined by least-squares as recommended by Chou (1992). Chandrasekhar means were used in both cases for the aerosol properties. The total spectral region diagnosed ranged between 175 nm and 692 nm. The two-band model divided this region at 322 nm. The six-band model subdivided the region between 175 nm and 322 nm into five bands, leaving a single band between 322-692 nm. The nine-band model further subdivided this last band into four bands.

Table 1. Three spectral band models used for diagnostic and radiative forcing calculations

Bands	Spectral Ranges (nm)
2	175.4 – 322.5 322.5 – 692.5
6	175.4 – 224.7 224.7 – 243.9 243.9 – 285.7 285.7 – 298.5 298.5 – 322.5 322.5 – 692.5
9	175.4 – 224.7 224.7 – 243.9 243.9 – 285.7 285.7 – 298.5 298.5 – 322.5 322.5 – 357.5 357.5 – 437.5 437.5 – 497.5 497.5 – 692.5

Table 2. Values obtained for sulfate and biomass burning aerosols by applying the cumulative diagnostic (Eqn. 4) over the 175 nm to 692 nm spectral region

Aerosol/Bands	2	6	9
Sulfate	7.938e-02	7.937e-02	7.135e-03
Biomass (20% Black Carbon)	1.122e-01	1.122e-01	1.040e-02

Going from one band to five bands between 175 nm and 322 nm made little difference to the magnitude of the diagnostic. This does not mean that having more than one band in this spectral region is unimportant for the accuracy of calculating fluxes or heating rates (Stamnes and Tsay, 1990; Chou, 1992); simply that it should not be important relative to the overlapping of ozone absorption with aerosol scattering and absorption. On the other hand, going from one band to four bands in the spectral region from 322 nm to 692 nm reduced the magnitude of the diagnostic by an order of magnitude. How this result carries over to actual aerosol forcing calculations is discussed below.

3. RADIATIVE FORCING CALCULATIONS — THE BOTTOM LINE

In order to further estimate the effects of the spectral bandings presented above on direct aerosol radiative forcing calculations, we performed several such calculations for global average, clear-sky conditions. The vertical profiles of temperature, ozone volume mixing ratio, and aerosol mass mixing ratio vertical profiles used for these calculations are shown in Figs. 2-4. Table 3 summarizes the results we obtained for net downward fluxes and aerosol radiative forcings at an assumed tropopause of 166 hPa. All calculations are for a solar zenith angle of 60° and a surface albedo of 0.159. The top-of-the-atmosphere solar fluxes were not reduced by the average daylight fraction. The spectral region covered is from 175 nm to 692 nm. Spectral bands are as discussed in Section 2 above.

Table 3: Net downward UV-visible fluxes and direct aerosol forcings at 166 hPa for three spectral models

Scenario/Band	2	6	9
Clear-Sky	211.372	211.901	207.777
Sulfate Aerosol Fluxes (W/m^2)	210.541	211.068	206.999
Sulfate Aerosol Forcing (W/m^2)	-0.831	-0.833	-0.778
Biomass Aerosol Fluxes (W/m^2)	211.496	212.026	207.922
Biomass Aerosol Forcing (W/m^2)	+0.124	+0.125	+0.145

As was the case for the diagnostic calculation above, adding more bands to the 175 nm to 322 nm has not resulted in a significant difference. Changing from one to three bands

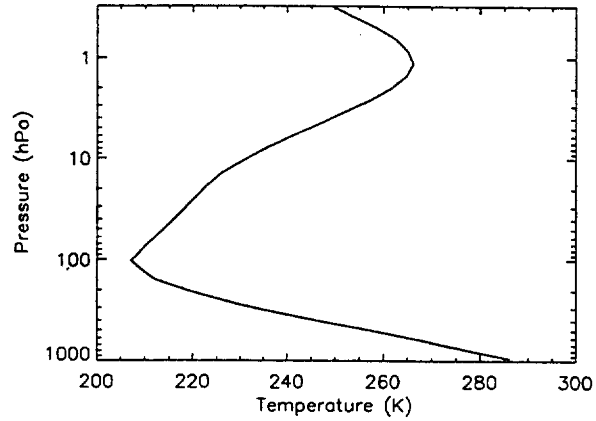

Figure 2. Global average vertical profile of temperature

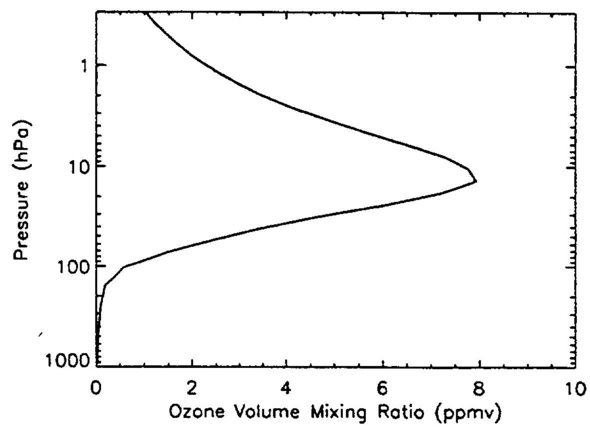

Figure 3. Global average vertical profile of ozone

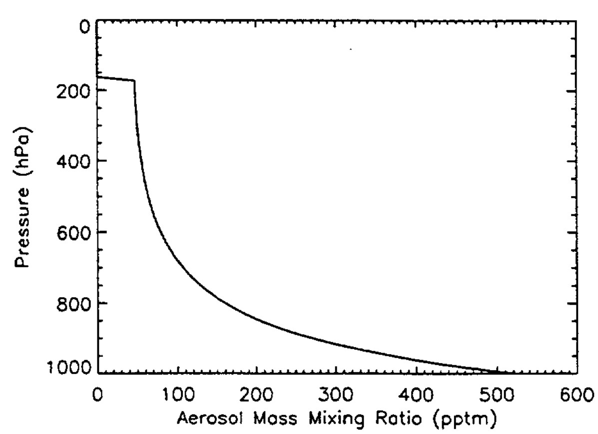

Figure 4. Global average vertical profile of aerosol mass derived from calculations of Chuang et al. (1995)

in the 322 nm to 692 nm resulted in a 6% decrease in forcing for the sulfate aerosol and a 16% increase in forcing for the biomass aerosol.

4. SUMMARY AND CONCLUSIONS

In this paper, we have developed a simple diagnostic to estimate the comparative accuracy of potential UV-visible spectral bandings before they are fully implemented in a radiative transfer model. The focus of the accuracy estimate is the overlap between spectrally dependent aerosol optical properties and other radiative species. We have verified that the relative results from this diagnostic are consistent with calculations of the direct radiative forcing for typical sulfate and biomass aerosols.

Our results show that the accuracy of aerosol forcing calculations are insensitive to the number of bands between 175 nm and 322 nm, but have significant sensitivity to the banding used between 322 nm and 692 nm. Errors obtained when using a single band for this latter region varied between 6-16%. Corresponding values of the banding diagnostic were on the order of 0.1 when one band was used between 322 nm and 692 nm. In agreement with the flux results, this was not significantly changed when the 175 nm to 322 nm region was split into five bands but was reduced to approximately 0.01 when the 322 nm to 692 nm region was split into three bands.

REFERENCES

Chou, Ming-Dah, 1992: a Solar Radiation Model for Use in Climate Studies, J. *Atmos. Sci.*, **49**, 762-772.

Chuang, Catherine C., Joyce E. Penner, Karl E. Taylor, Allen S. Grossman, and John J. Walton, 1995: An *Assessment of the Radiative Effects of Anthropogenic Sulfate-Containing Aerosols*, Submitted to J. Geophys. Res., Also Lawrence Livermore National Laboratory Report UCRL-JC-122600.

Stamnes, K., and S.-C. Tsay, 1990: Optimal Spectral Resolution for Computing Atmospheric Heating and Photodisssociation Rates, *Planet. Space Sci.*, **38** (6), 807-820.

WMO, 1985: Reference Solar Irradiance, Rayleigh Scattering, O_2, and O_3 Cross Sections, *Atmospheric Ozone 1985*, WMO Global Ozone Research and Monitoring Project — Report No. 16, Vol. I., pp. 355-362.

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